# Testing average then retrieve approach with PCRTM with CALIPSO/ClouduSat clouds and AIRS spectral radiances

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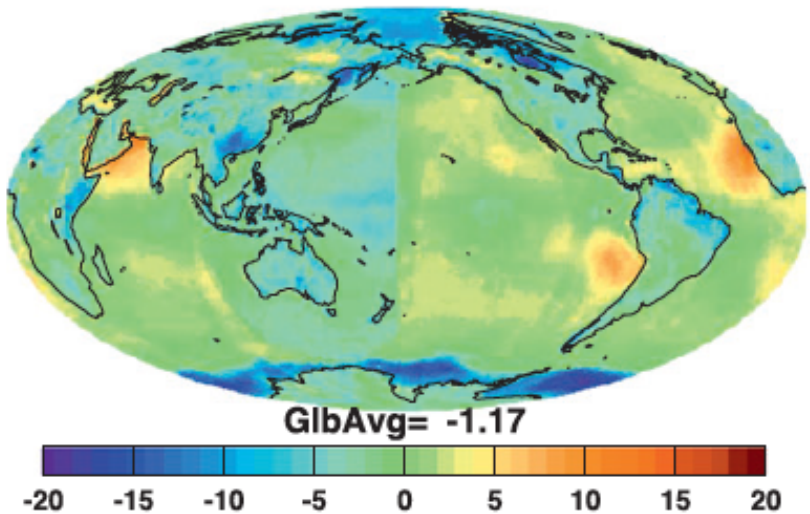
# Objective of this work

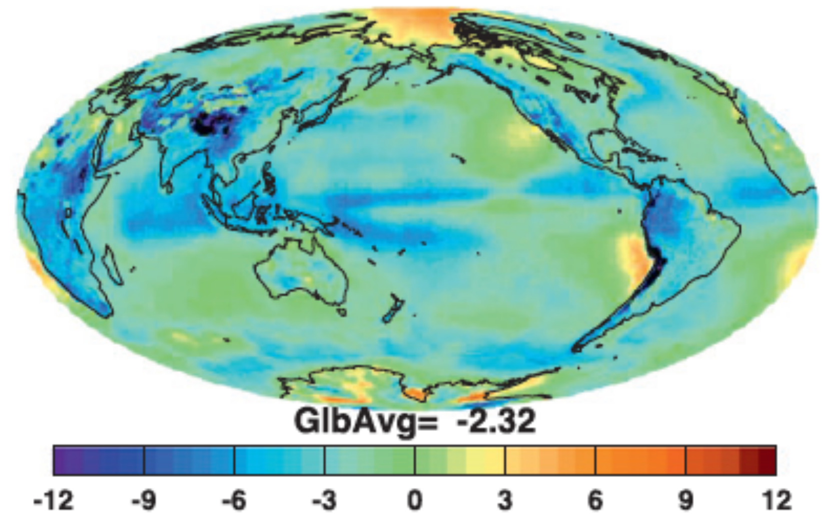
- Average-then-retrieve approach used in the CERES project (EBAF-surface)
- Evaluate the effect of the covariance matrix used in the retrieval

# TOA irradiance difference

Computed – observed TOA SW irradiances




Computed – observed TOA LW irradiances

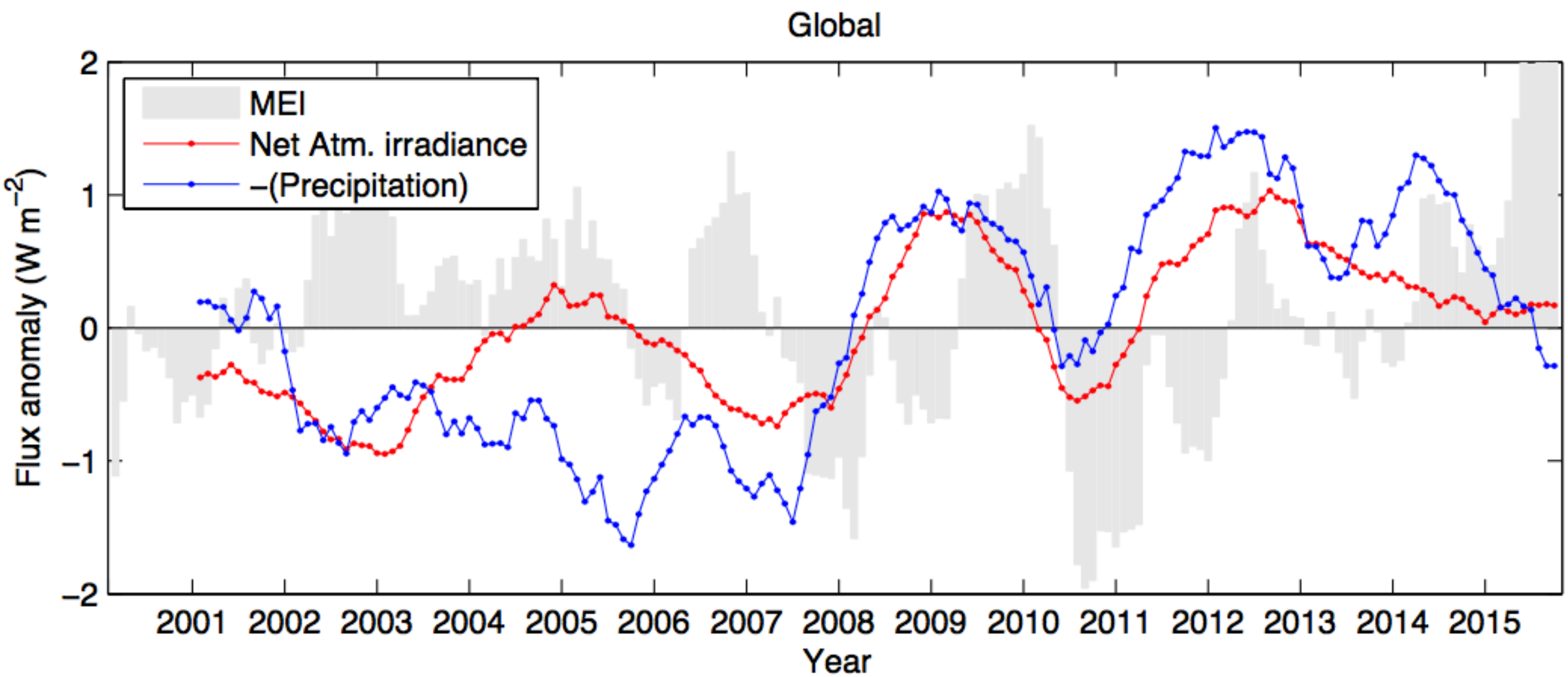



Mean of monthly 1°×1° computed – observed TOA irradiance over 120 months

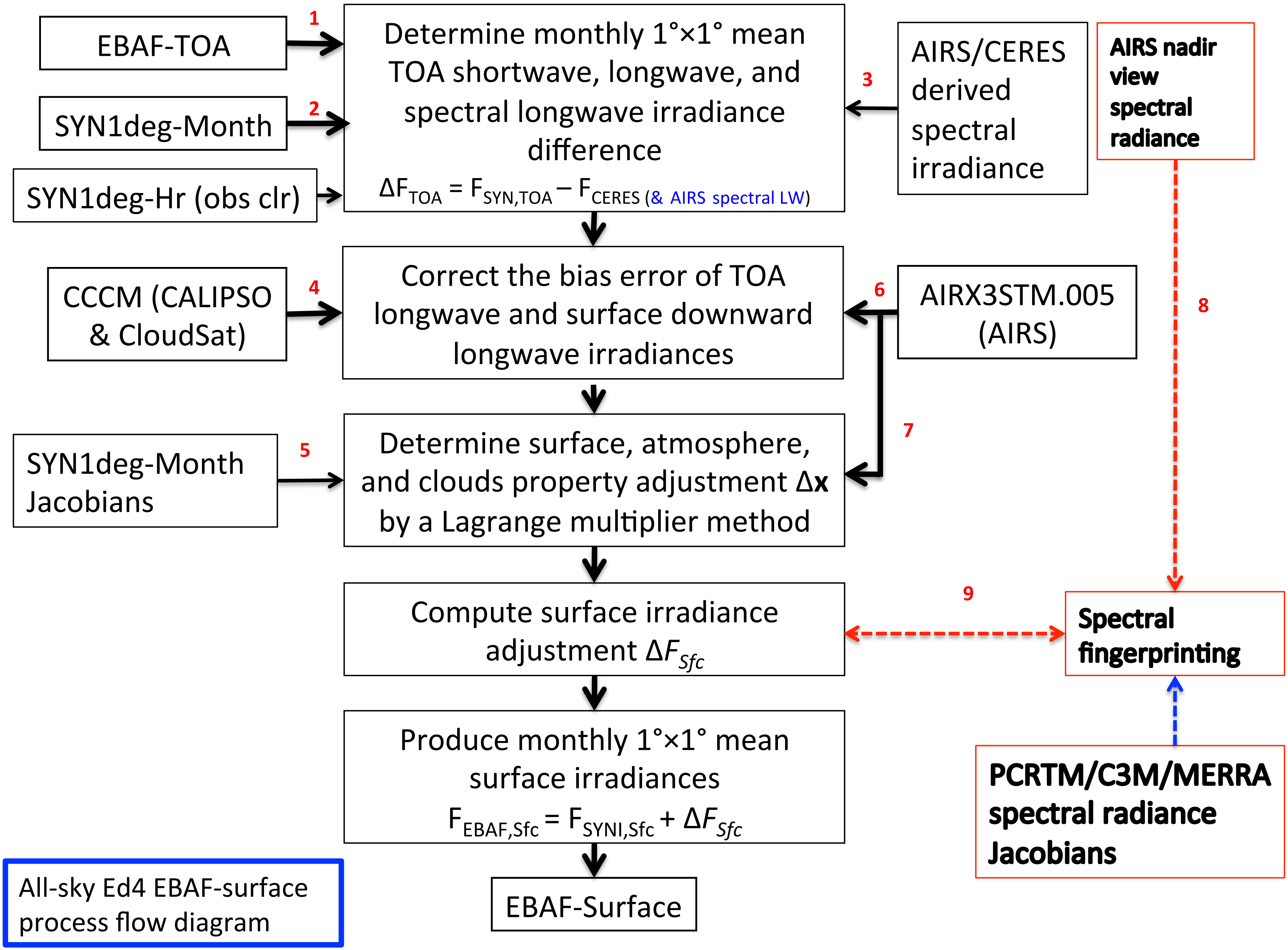
- The difference is largely due to errors in inputs used for irradiance computations
- Need to adjust T, q, and cloud and surface properties to match TOA irradiances.

# Atmospheric irradiance divergence vs. precipitation anomalies

Radiation is probably not responsible for the 15 $Wm^{-2}$ surface energy balance residual, but the error in anomalies is less certain.
Current accuracy level is ~0.8 $Wm^{-2}$ per decade (at a 60% confidence level) for both surface downward LW and SW irradiances (CERES white paper) while precipitation changes at the rate of ~0.3 $Wm^{-2}$ per decade (2% $K^{-1}$)




With 12 month running mean
Surface sensible heat anomalies are missing


EBAF-TOA
SYN1deg-Month
SYN1deg-Hr (obs clr)
1
2
3
Determine monthly 1°×1° mean TOA shortwave, longwave, and spectral longwave irradiance difference
$\Delta F_{TOA} = F_{SYN,TOA} - F_{CERES}$ (& AIRS spectral LW)
AIRS/CERES derived spectral irradiance
AIRS nadir view spectral radiance
CCCM (CALIPSO & CloudSat)
4
Correct the bias error of TOA longwave and surface downward longwave irradiances
6
AIRX3STM.005 (AIRS)
8
7
SYN1deg-Month Jacobians
5
Determine surface, atmosphere, and clouds property adjustment Δ**x** by a Lagrange multiplier method
Compute surface irradiance adjustment $\Delta F_{Sfc}$
9
Spectral fingerprinting
Produce monthly 1°×1° mean surface irradiances
$F_{EBAF,Sfc} = F_{SYNI,Sfc} + \Delta F_{Sfc}$
PCRTM/C3M/MERRA spectral radiance Jacobians
All-sky Ed4 EBAF-surface process flow diagram
EBAF-Surface

# Spectral radiance computation

- C3M (CALIPSO, CloudSat, and MODIS derived cloud fields)
- MERRA (T and Q)
- Nadir view spectral radiance and Jacobians by PCRTM
- Sampling is the same as nadir view AIRS spectral radiance

# Main Elements

- PCRTM over AIRS channels, thermal IR only
  - 2378 channels ( 649-1613 / 2181-2665 $cm^{-1}$)
- CALIPSO, CloudSat, CERES, MODIS (C3M) data product
  - near nadir FOVs
  - cloud properties: fraction, tau, height, phase, Re/De
- GMAO MERRA assimilation
  - ( 0.66 deg x 0.50 deg x 72 levels)
  - Temperature , Humidity , Ozone profiles
  - Skin Temperature
- IASI-derived surface emissivity (Zhou et al. 2013) for 18 IGBP types at PCRTM 493 monochromatic wavenumbers

# Additional Details

- Up to 4 (Clear, Low, Mid , High) cloud columns per FOV
  - Cloud fraction weighted average for the FOV total-sky spectral radiance.
- Jacobians for each sub-FOV scale cloud column (43 total Jacobians):
  - Temperature and Humidity 15 levels (15 ×2)
  - Skin temperature
  - Cloud : Fraction , Pressure, Cloud Tau , Particle Size (4×3)
- Computation for a nadir view angle made for slightly (< 15deg) off-nadir FOV atmosphere properties from C3M.
- Gridding to 2.5x2.0 deg grid, individually averaged for ascending and descending over 16 day period to match gridded AIRS nadir radiance product provided by X. Huang.
  - Gridded AIRS from nadir FOV locations, slight spatial mismatch between AIRS nadir view FOV location and C3M footprint location
  - Two 16 day periods : Jul 12-Jul27 and Jul28-Aug12 2006
- Spectral radiances and Jacobians are further averaged to 10 x 10 deg.

# Retrieval

$$\mathbf{a} = (\mathbf{S}^{\mathrm{T}}\mathbf{S} + \lambda\mathbf{H})^{-1}\mathbf{S}^{\mathrm{T}}\overline{\Delta\mathbf{I}},$$

**ΔI**: Difference of two 16 days mean nadir view radiances, descending (nighttime) or ascending (daytime)

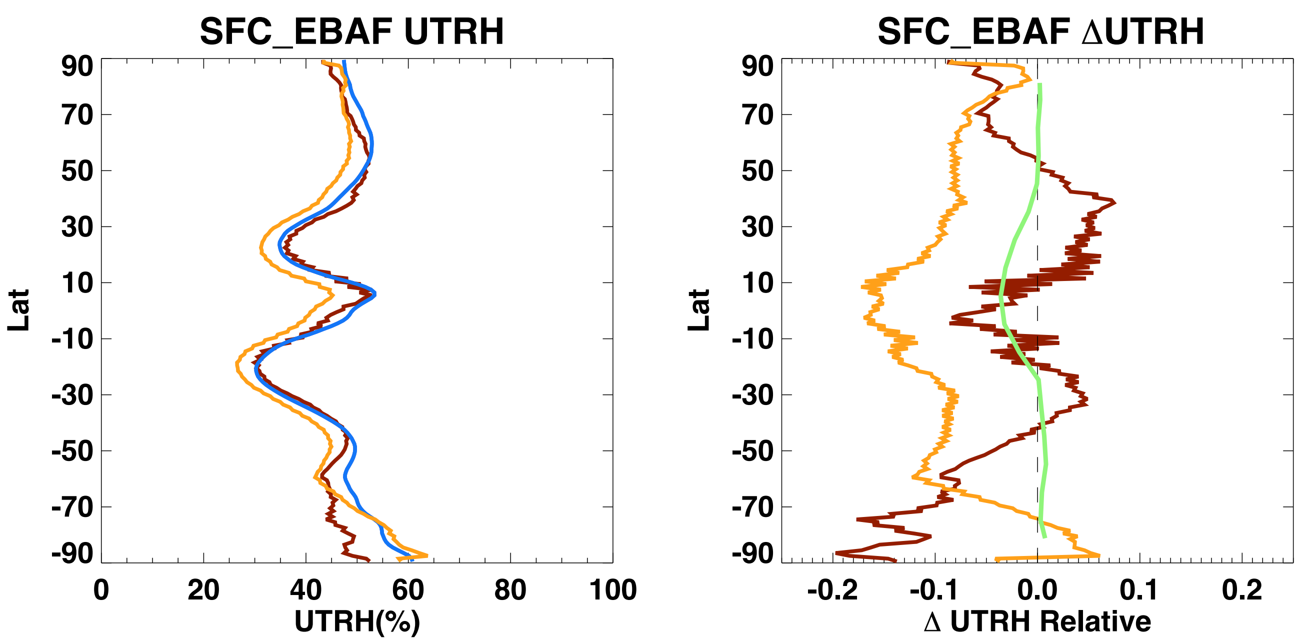
**S**: 10 degree zonal mean kernels (Jacobians)
Skin temperature, 15 layers of T and Q,
3 cloud types (high, mid, and low) of top height, optical thickness, particle size, and cloud fraction

Retrieve 43 variables for 10 degree by 10 degree regions over oceans and average for zonal means

T and Q layer boundary pressure
0.005, 10, 50, 100, 200, 300, 400, 500, 600, 700, 800, 850, 900, 950, 1000, 1100

# UTRH Adjustment

- Unadjusted MOA Geos5.4.1
- Pre-tuning to Modified AIRSL3 Product UTRH
- Lagrange Multiplier solution Airs Spectral Flux
- Fingerprinting to AIRS Radiances using PCRTM spectral model &C3M data

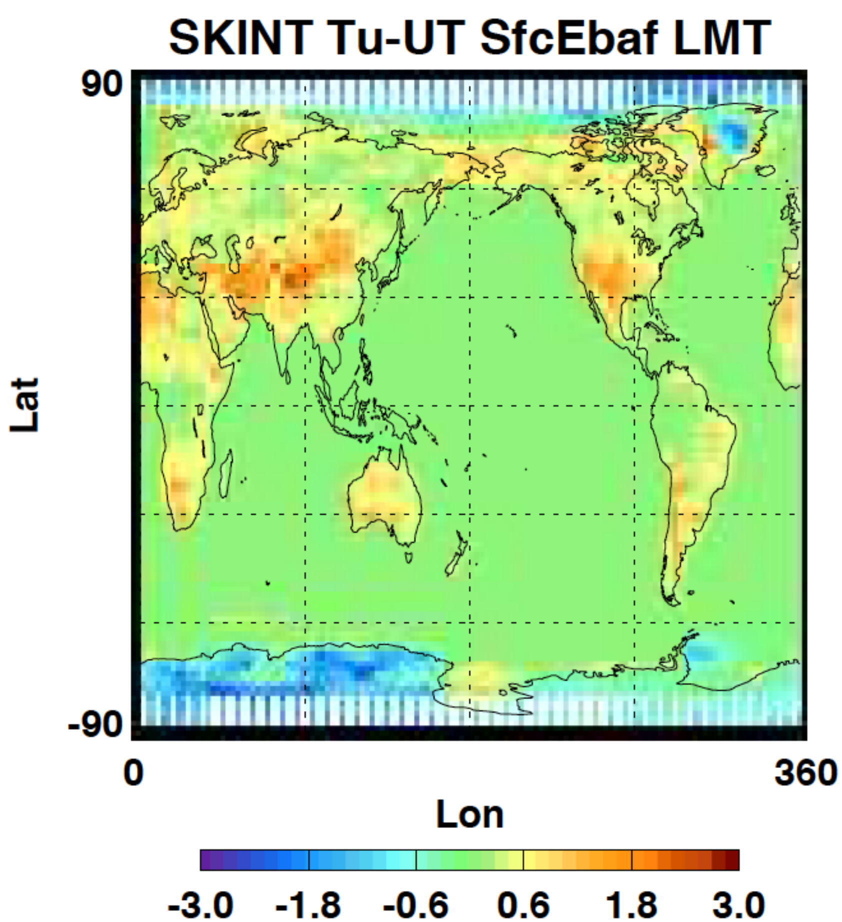



2008 annual mean

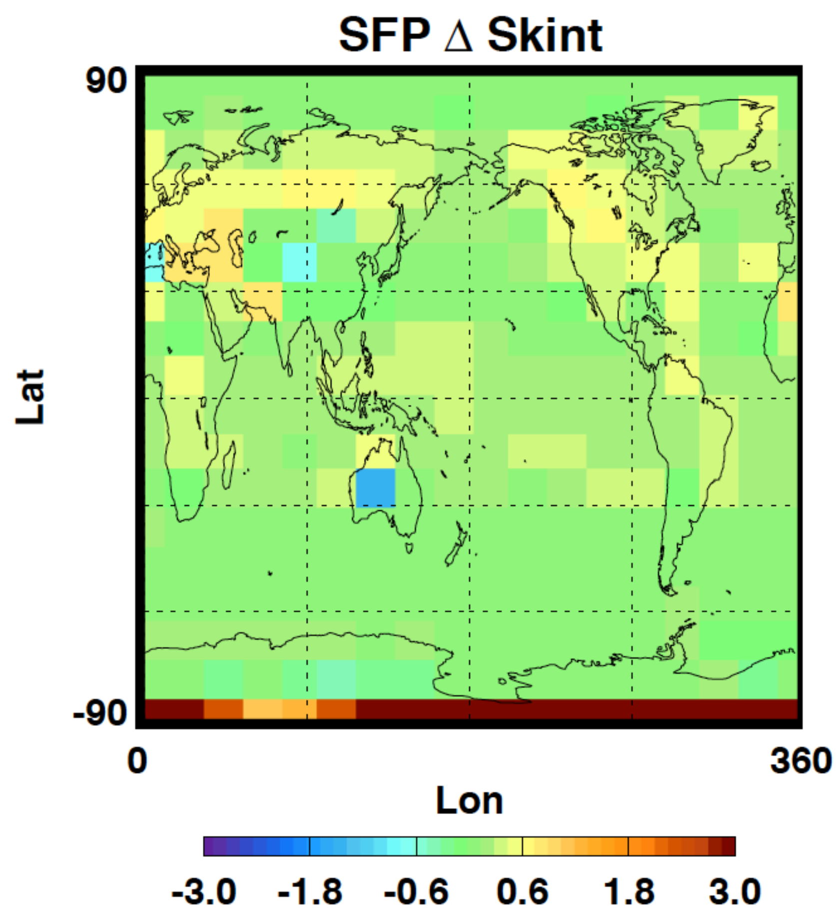
All three different approaches suggest that GEOS-5.4.1 upper tropospheric humidity is too large

# Skin temperature adjustment

Adjustment by Lagrange multiplier




Adjustment by radiance fingerprinting




Land height is not properly handled in the current algorithm

# Does including a covariance matrix reduce the retrieval error?

# Kernel Matrix **S**

$$\mathbf{a} = (\mathbf{S}^{\mathrm{T}}\mathbf{S} + \lambda\mathbf{H})^{-1}\mathbf{S}^{\mathrm{T}}\overline{\Delta\mathbf{I}},$$

- Retrieval results is very sensitive to **S**, which is contains spectral radiance change due to a perturbation of variable x by Δ
- Best result seems to be achieved when the elements of **a** are close to 1 (i.e. needs a good initial guess on Δ).
- Including a covariance matrix

$$\mathbf{a} = \left(\mathbf{S}^{T}\Sigma^{-1}\mathbf{S} + \lambda\mathbf{H}\right)^{-1}\mathbf{S}^{T}\Sigma^{-1}\Delta\mathbf{I}$$

- Need to form a covariance matrix Σ

# Covariance matrix to correlation matrix

- **S** is a $m$ by $n$ matrix and $\Sigma$ is a $m$ by $m$ matrix and $\Delta\mathbf{I}$ is a vector with the length of $m$, where $m$ is the number of wavenumbers and n is the number of variable to be retrieved.
- We assume that the dominant cause of the error is the sum of the error in each kernel $\Sigma = \Sigma_1 + \Sigma_2 + \ldots$.
- $\Sigma_i$ is computed by $\Delta\Sigma_i^T\Delta\Sigma_i / (l\text{-}1)$where $\Delta\Sigma_i$ a $l$ by $m$ matrix contains deviation of the $i$th component of the kernel from the climatological value. $l$ is the number of $\Delta\Sigma$ used to the compute covariance matrix
- To minimize the effect on the magnitude of the elements of **S**, we use the correlation matrix $\mathbf{R}_i = \mathbf{D}^{-1}\Sigma_i\mathbf{D}^{-1}$, where elements of **D** are all 0 except for the diagonal terms. The diagonal terms are SQRT of the corresponding diagonal term of $\Sigma_i$.
- **R** is the mean of $\mathbf{R}_1$, $\mathbf{R}_2$, $\mathbf{R}_3$…

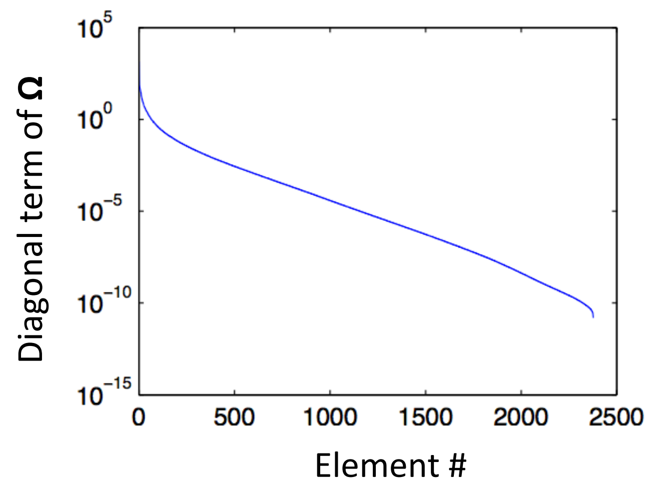
# Singular value decomposition of the correlation matrix

$$\mathbf{a} = \left(\mathbf{S}^T\mathbf{R}^{-1}\mathbf{S} + \lambda\mathbf{H}\right)^{-1}\mathbf{S}^T\mathbf{R}^{-1}\Delta\mathbf{I}$$

where $\mathbf{R}=\mathbf{U}\boldsymbol{\Omega}\mathbf{V}^T$, and $\mathbf{R}^{-1}=\mathbf{V}\boldsymbol{\Omega}^{-1}\mathbf{U}^T$

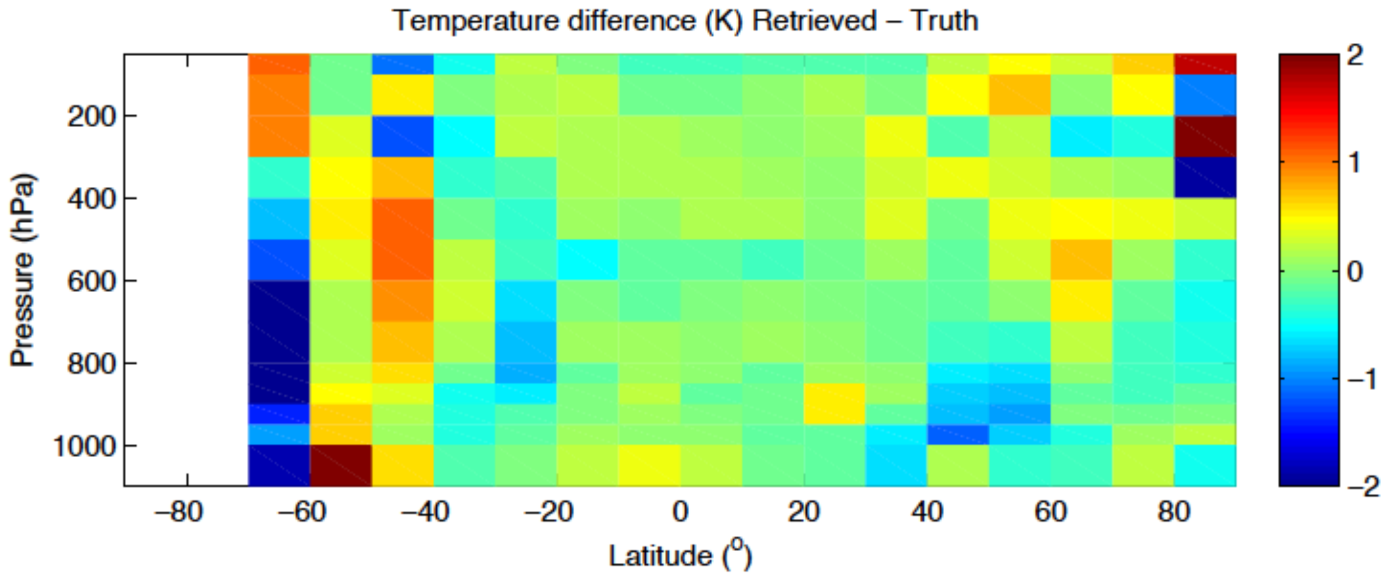
Keep only 500 diagonal terms of $\boldsymbol{\Omega}$ (total number of wavenumbers = 2378)

Correlation matrix **R** is a *m* by *m* matrix that contains the correlation of errors between wavenumbers

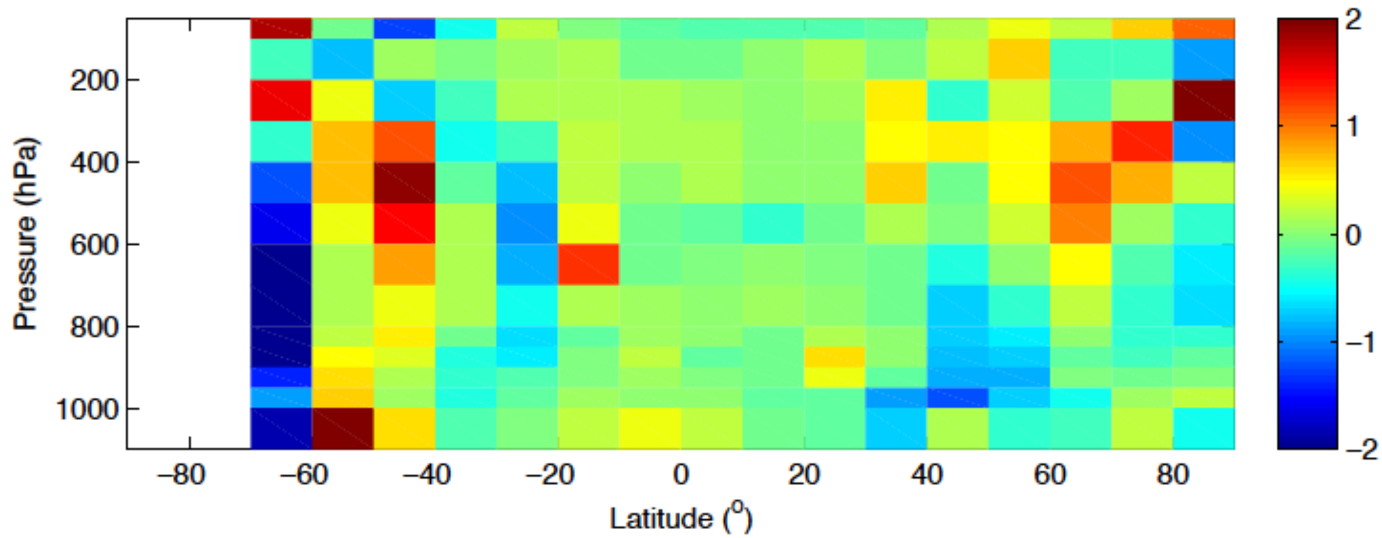


# Temperature difference (over ocean)

With correlation matrix

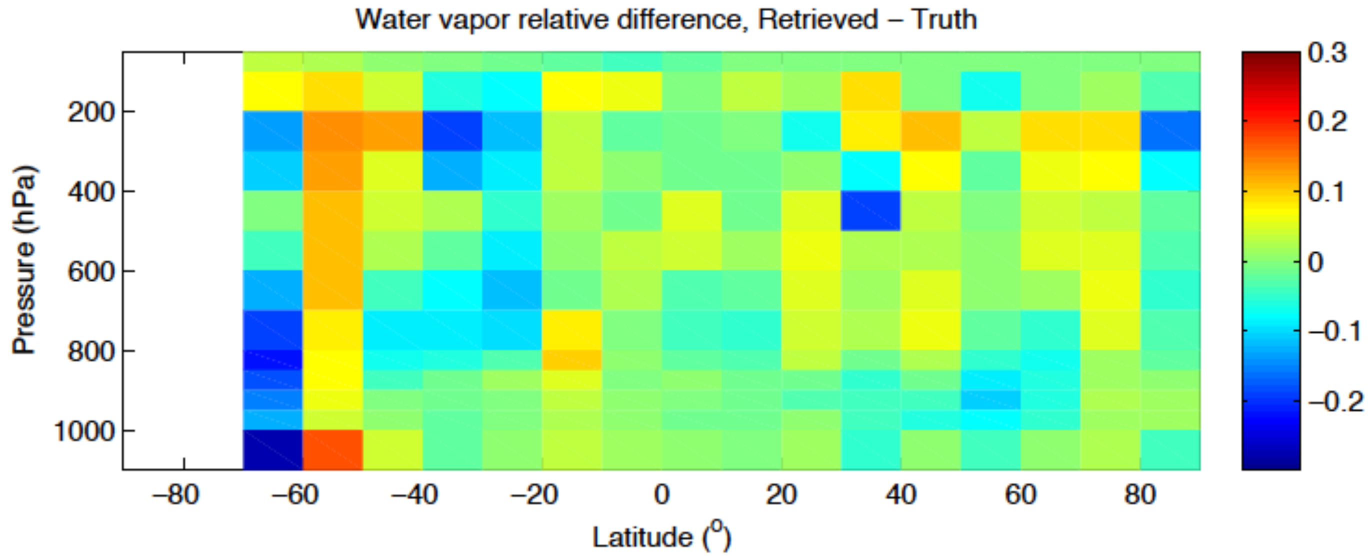



Without correlation matrix

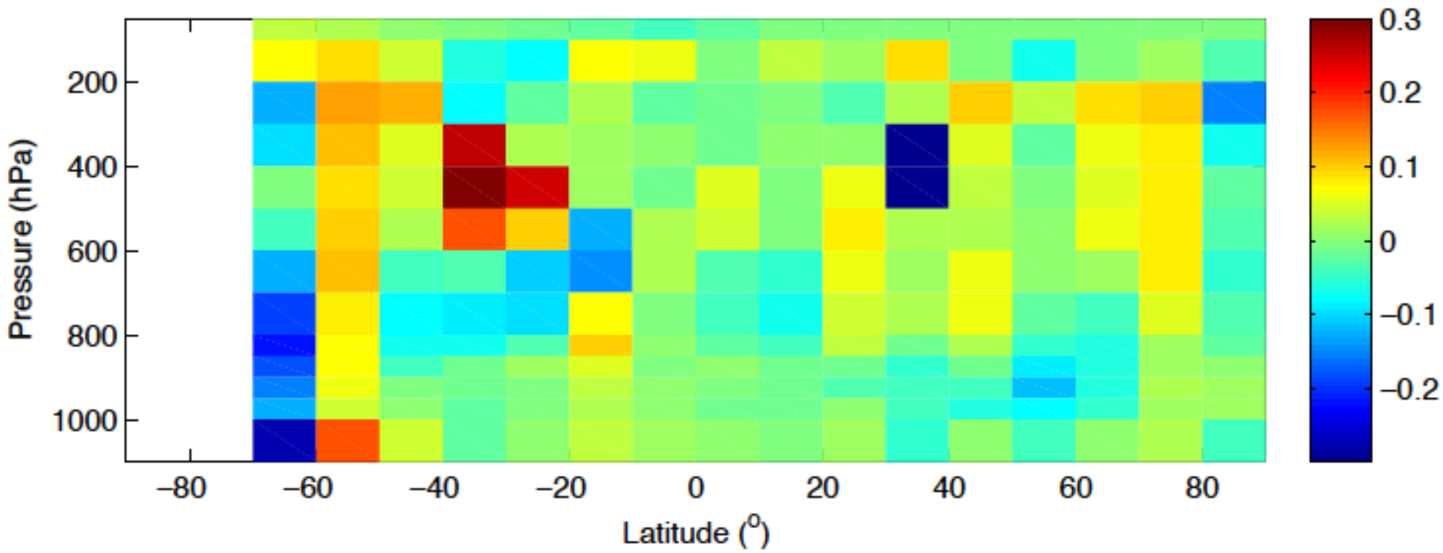


# Relative water vapor mixing ratio difference

With correlation matrix




Without correlation matrix



# White paper on average-then-retrieve approach QESO

$$\frac{\Delta t}{\Delta t_p} = \left( 1 + \frac{\sigma_{cal}^2 \tau_{cal} + \sigma_{sam}^2 \tau_{sam} + \sigma_{a\lg}^2 \tau_{a\lg}}{\sigma_{\mathrm{var}}^2 \tau_{\mathrm{var}}} \right)^{1/3}$$

The goal is to get

$$\sigma_{a\lg}^2 \tau_{a\lg} / \sigma_{\mathrm{var}}^2 \tau_{\mathrm{var}} \approx 1$$

This gives a 10 year delay to to detect a trend if a perfect instrument takes 30 years to detect a trend

# Summary

- The difference between computed and AIRS-observed spectral radiances was used to infer the error in T, q, cloud and surface properties used in radiance computations.
- Results are very sensitive to the magnitude of the kernel matrix **S** used for the retrieval
- The effect of the covariance (correlation) matrix was tested. Including the correlation matrix in the inversion improves the result.
- The most important factor affecting the result is to set kernels in **S** so that the elements of **a** is close to unity (needs a good initial guess).